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An Apparatus for the Study of the Drying Rates of Sheet Rubber

R. S. GALE

The apparatus is an experimental drier in which the drying conditions can be controlled in the range from normal atmospheric temperature and humidity to 200°F and 70% R.H. Means for measuring and controlling temperature and humidity, and for weighing sample sheets, are described.

Exploratory investigations into the factors involved in an experimental study of the drying of sheet rubber (GALE 1959) showed that both the temperature and the humidity of the drying air are of major importance in determining drying rates. It was also shown that small changes in equilibrium water content due to variation in humidity are associated with large changes in drying rate. This emphasised the need for accurate water-content measurement as a first step towards establishing a correlation between equilibrium water content and drying rate and therefore suitable methods of determining the wet and dry weight of a sample were needed. A method of determining dry weight has already been described (GALE 1959). The apparatus described below enables the wet weight of samples to be determined accurately during drying, under conditions of temperature and humidity up to 200°F and 70% R.H.

GENERAL DESIGN

The general arrangement is shown diagramatically in Figure 1. Air is blown by a centrifugal fan(1) through a series of coiled nichrome wire electric heaters(2), into a section(3) where live steam may be injected. The steam discharges from 1/16-inch diameter holes in the top of the injection pipes which are lagged to minimise condensation and fitted with steam traps to discharge any condensate which is formed. After the air has passed through a 'disc-and-doughnut' baffle

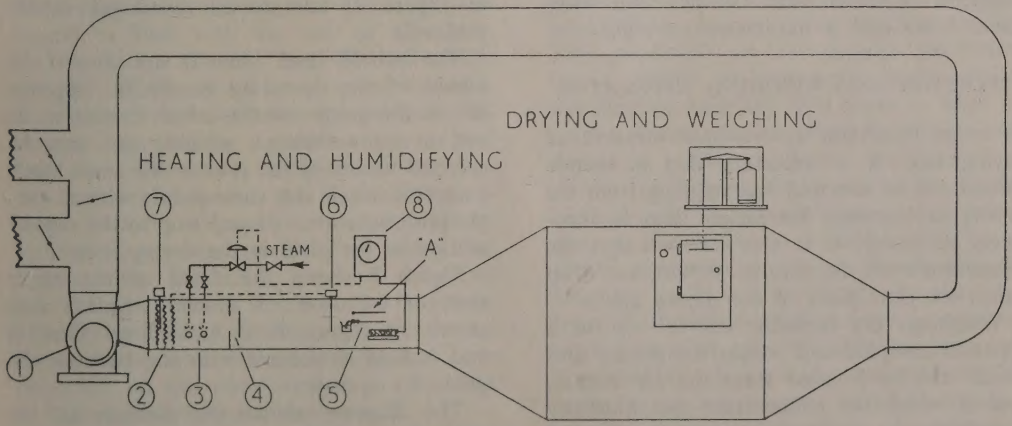

Figure 1. General arrangement of drying apparatus.

mixing section(4), its humidity is measured with wet and dry bulb thermometers(5), observed through a window which can be heated to prevent condensation on the inner surface. The air flow discharges into the main drying zone and from there continues through a return duct to the suction side of the fan. The ratio of fresh to recirculated air is controlled by the settings of three butterfly valves.

The dry bulb temperature is controlled by an on-off thermostat(6), operating a 5 kW control load to which can be added base loads up to 20 kW in units of 1 kW. Protection against overheating in the event of air-flow failure is provided by a thermostat(7) placed amongst the heating elements; a main circuit breaker operates when the temperature rises above a predetermined maximum. The wet bulb temperature is controlled by regulating the steam flow with an air-operated proportional controller(8).

Twelve sample sheets are hung in the drying zone parallel with the air flow and can be removed for weighing by a mechanical selector.

The heating and humidifying section is lagged with 2-inch Viceroy cellular sheets, the ducts with 1-inch Viceroy, and the drying chamber with 2 inches of tamped magnesia asbestos held between the sheet metal body and a hardboard covering.

SELECTOR AND WEIGHING APPARATUS

In order to obtain an accurate measure of drying rate, it is necessary that a sample should not be removed for weighing from the drying environment for longer than is absolutely necessary. It is also essential that the temperature of the sample should not drop below the dew point of the drying air.

Weighings are therefore carried out in a separate compartment within the drying unit which can be isolated from the air stream, and in which the temperature and humidity are similar to the drying air. A mechanical selector eliminates the need for any handling of the sheet. Figure 2 shows the general arrangement of the samples, the weighing compartment, and the selector mechanism.

The Selector Mechanism

Each sheet (6 inches × 10 inches) is hung from four hooks which are connected to a wire(1) shaped in the manner shown in the enlarged drawing of items (1) and (2) in Figure 2. The hooks are located on the wire but are free to pivot, thus allowing them to move as the sheet shrinks during drying. When the sheet is in the drying zone the wire is supported on two fixed hooks(2). Behind the row of sample sheets is a bar(3) on which runs a tube(4). A plate(5) is fixed to the tube and carries an arm(6) which is free to rotate on a small shaft and thus stays horizontal whatever the angular position of the plate. To remove a sheet from its position in the drying zone, the plate is moved to a position opposite the sheet and lowered by rotating the tube(4), until the arm(6) is opposite the sheet-supporting wire(1). The arm is then manipulated to lift the wire, the plate carrying the sheet is returned to its original vertical position, and the tube is withdrawn so that the sheet passes through a rectangular aperture into the weighing compartment. The aperture is automatically sealed by the plate, the raised rim of which (see 23 in Figure 4) compresses the foam rubber gasket(7).

The tube(4) and plate(5) are moved by means of the operating handle(8). Opposite this is the guide arm(9), which carries at its end a counterbalance weight, and can be engaged in any of the slots in the sheet metal guide(10). Each slot corresponds with a sample position and is shaped to give the correct motion of the plate in the drying zone.

Figure 3 shows the detail of the upper ends of the slots. A slotted strip(12) (not shown in Figure 2) is located on pins(11) and is held in contact with the back of the guide by springs.

The diagram shows the motions of the guide bar and the strip, and the notes give the corresponding motions in the drying zone. The purpose of the strip is to prevent fouling

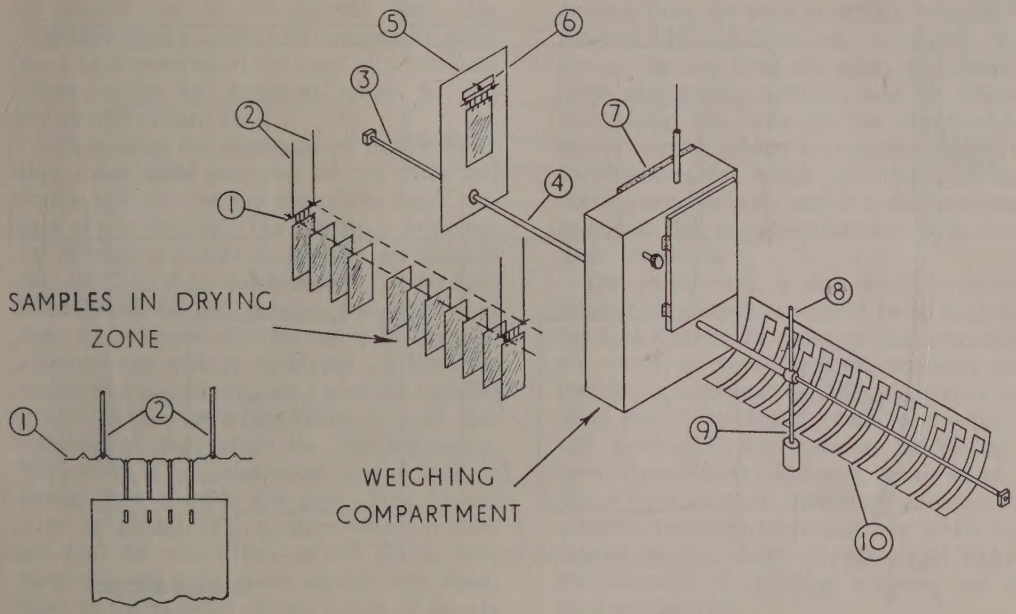

Figure 2. Sheet selector and weighing compartment, isometric view.

of the fixed hooks(2) when a sample is being returned to its position in the drying zone.

The Weighing Apparatus

The weighing compartment projects inside the drying unit and the outer face, which is lagged, is flush with the wall of the drier. On this face a door is fixed through which samples can be entered or removed by hand. The door is constructed of two sheets of perspex separated by a sealed air space and fixed to a steel frame. Samples can therefore be inspected when they are in the compartment. In the air space is an electric heater formed by a wire stretched in serpentine fashion over the whole area of the door between two rows of small porcelain insulators. By controlling the supply to this heater through a variable voltage transformer, condensation on the inner surface of the door at high humidities can be prevented.

As mentioned above, the sample sheet enters the weighing compartment through an aperture in the back of the compartment. The sheet is suspended from the arm(6) which is carried by the plate(5) which in turn forms the door for closing the aperture. Figure 4 shows the weighing apparatus and a sheet in position on the arm. The sheet is transferred from the arm to the weighing hook(28) by means of the transfer arm(29). The spindle(32) of the transfer mechanism has a pin(30) which engages in the slot of the locating tube(31). The sheet is lifted by anti-clockwise rotation of the knob(33), withdrawn by pulling the knob, and lowered on to the weighing hook by clockwise rotation of the knob. The transfer arm is then moved clear of the sheet by a further withdrawal. While the sheet is being transferred, the weighing hook is held steady by the cross bars(15) and (26) which engage in two sets of V-guides(16) and (27). For weighing, the V-guides(16) are lowered, thus allowing the hook(14) to rest on the hook(13) which is attached to the balance arm. On release of the nomal balance arrestment mechanism, the balance is free to swing and weighing

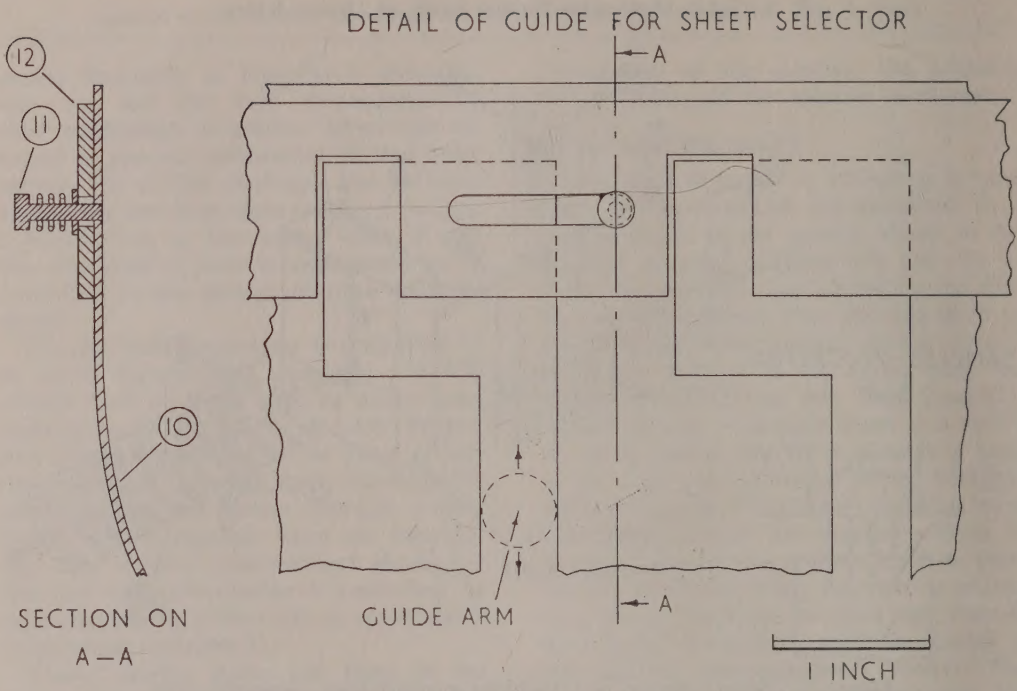

Figure 3. Detail of guide for sheet selector.

is carried out in the normal way. The V-guides(16) are raised and lowered by rotating a cam mounted at the front of the balance which moves the lever(18), which in turn moves the collar(17).

When using the apparatus at high humidities, water could condense on the wires and hooks and also on the top of the inner surface of the tube(24). The former is overcome by blowing a stream of hot dry air through the duct(21). Any condensation on the tube is collected in the annular trough(25) and runs away harmlessly through a U-tube. To minimise the leakage of humid air from the weighing compartment, the top of the tube(24) is fitted with a cover(22) having a small central hole through which the wire(19) passes. The cover is so constructed that it can be moved from outside the duct. This enables it to be placed in a position where it does not foul the wire. The position of the wire relative to the tube varies slightly with variations in the position of the centre of gravity of the sample sheet. A similar cover(20) is fitted at the top of the duct.

An Oertling air-damped balance with a capacity of 250 g and an illuminated scale of 0–0.500 g is used.

The whole operation of bringing a sheet from the drying zone, weighing it and returning it to its original position takes about one minute.

OPERATING CONDITIONS AND ACCURACY OF MEASUREMENT AND CONTROL

Measurement of Temperature and Relative Humidity

The relative humidity in the drying zone is determined from the dry bulb temperature and the absolute humidity, deduced from the wet and dry bulb temperatures measured at point A in Figure 1. (The dry bulb temperature in the drying zone is slightly lower than at point A).

The measurement of wet bulb temperature requires considerable care. The wet bulb temperature is a dynamic equilibrium temperature at which the latent heat of the water evaporated from the wick is exactly balanced by the heat received. This heat is supplied from the air passing over the wick, by radiation from surrounding surfaces, and by conduction along the stem of the thermometer. Psychrometric tables are usually based on conditions under which radiation and conduction are negligible and it is thus necessary to ensure that measurements are made under these conditions.

The requirement is that the rate of heat transfer by convection should be so high that the heat transfer by radiation and conduction are small in comparison. Convection heat transfer is increased by high air speeds and small size of thermometer bulb, and radiation and conduction are reduced by having a small thermometer. Although an air speed of 600 ft/min. is often quoted as adequate for accurate readings, each case has to be considered on its merits to allow for varying temperatures of radiating surfaces and for thermometer size.

The wet bulb thermometer used in this case is a standard Casella sling psychrometer thermometer 16 cm in length with a bulb 16 mm long and $1\frac{1}{2}$ mm diameter, fitted with a tubular wick. With an air speed in the measuring zone of about 800 ft/min., this gives reasonably accurate readings over the whole temperature range. The dry bulb thermometer is a mercury-in-glass thermometer fitted with a radiation shield.

The psychrometric tables of ZIMMERMAN and LAVINE (1945) are used for conversion of the wet and dry bulb temperatures into relative humidity. These tables are stated to be based on those given by MARVIN (1941), but Marvin only quotes data up to 140°F and the basis of Zimmerman and Lavine's tables above 140°F is not clear. Above 140°F the tables agree closely with those given by the INSTITUTION OF HEATING AND VENTILATING ENGINEERS (1955).

Having selected a set of psychrometric tables and a system of measurement, the two can be compared by heating atmospheric air of known absolute humidity to fixed temperatures and noting any discrepancy between

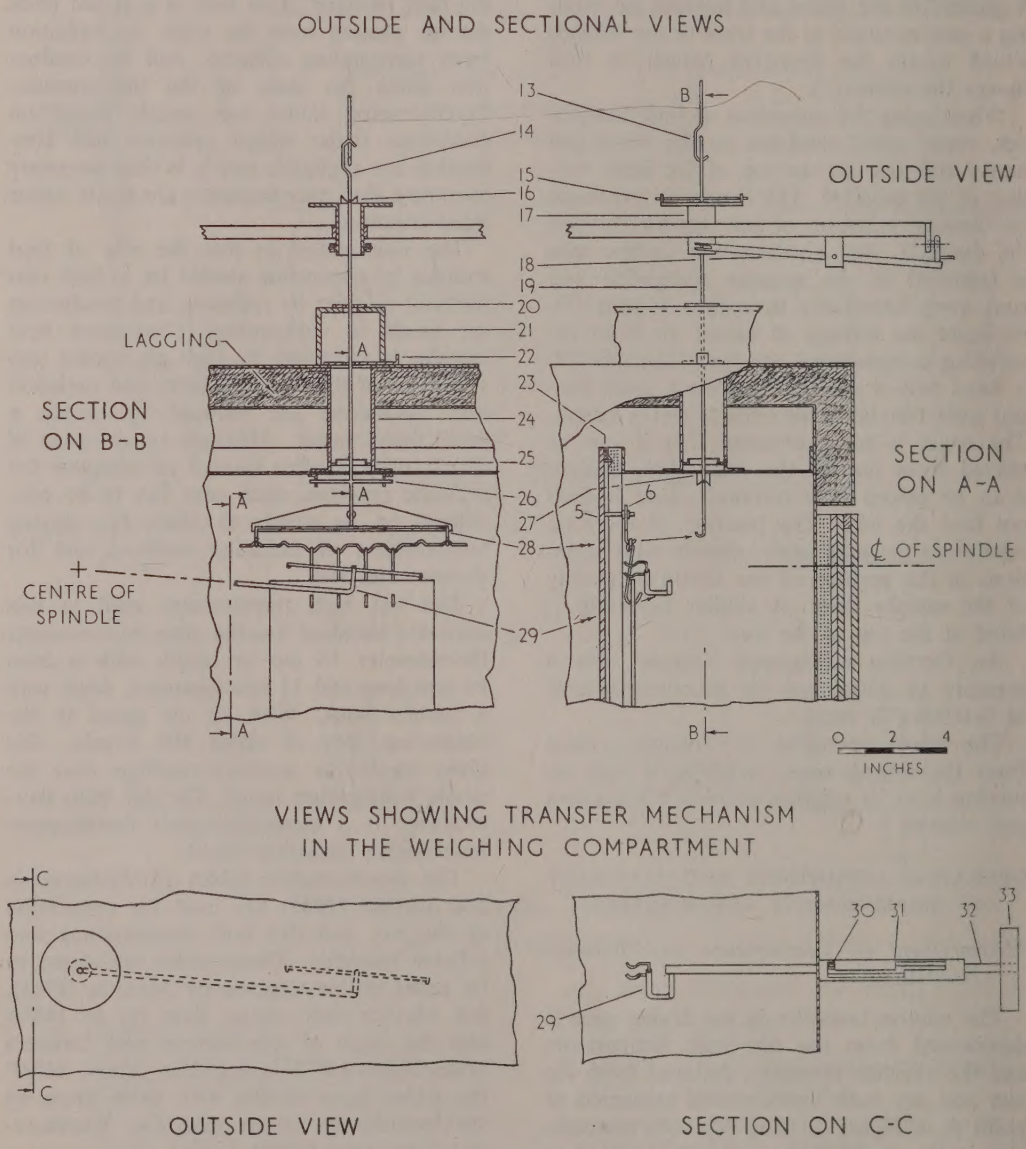

Figure 4. Weighing apparatus.

the wet and dry bulb readings and those predicted from the tables. The results of tests in which the absolute humidity of the air (c. 0.019 lb water per lb dry air) was determined by sling psychrometer at c.88°F, showed excellent agreement up to 160°F. At 200°F dry bulb, the wet bulb temperature was higher than predicted but the error was only such as to give an apparent humidity one unit of percentage relative humidity higher than the predicted value. Under these conditions, where the difference between the dry and wet bulb temperatures is greatest, radiation and conduction errors are at a maximum.

The humidity measuring apparatus in conjunction with the tables of Zimmerman and Lavine therefore give a high degree of accuracy.

In the Kuala Lumpur laboratories the barometric pressure lies well within the range 1000 to 1020 millibars but this deviation from the pressure of 1013 millibars for which the tables are calculated does not warrant correction of the readings. Calculations show that the error due to a change from 1000 to 1020 millibars is not more than 0.3% R.H. for humidities above 20% R.H. and temperatures above 100°F.

Control of Temperature and Relative Humidity

The on-off thermostat controls the dry bulb temperature with a range of $\pm$ 0.5°F. Since the bulb of the wet bulb controller does not satisfy the conditions for accurate measurements mentioned above, the controller is set to give the desired reading of the accurate wet bulb thermometer. The range of control is $\pm$ 0.25°F., and manual adjustments to correct for drift in the average temperature maintain the variation of the latter to within $\pm$ 0.5°F of the desired value.

It is estimated that the relative humidity in the drying zone is kept within $\pm$ 2% R.H.

Weighing

The reading of the balance is affected by slight leakage of air from the weighing compartment and by the air stream which prevents condensation on the wire. The errors are not more than c.15 mg and are allowed for by setting the balance at zero under conditions identical to those which will obtain when samples are being weighed.

The balance reading has to be corrected for buoyancy effects caused by the air surrounding the sample being at a different density from that surrounding the weights. For instance, a sample weighing 50 g at 100°F and 60% R.H. will have an apparent weight 20 mg greater when weighed at 200°F and 70% R.H.

Experiments have shown that the effect of the higher ambient temperatures on the balance itself does not affect the readings by more than 1 or 2 mg.

It is estimated that the overall accuracy of weighings is of the order of $\pm$ 5 mg, i.e. $\pm$ 0.01% for a sample of 50 g.

ACKNOWLEDGEMENTS

The author wishes to thank Mr W. G. Wren, Head of Chemical Division for his encouragement during the design of the apparatus.

The author is also indebted to Inche Abu Noh bin Abu Bakar who constructed the selector and weighing apparatus in the workshops of the Chemical Division and suggested various features of the design.

Chemical Division
Rubber Research Institute of Malaya
Kuala Lumpur *January 1960*

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Interactions of Lime and Molybdate in the Nutrition of Centrosema Pubescens and Pueraria Phaseoloides

G. A. WATSON

Two pot culture experiments are reported, in which the effects of applications of lime and sodium molybdate on the growth and nutrient status of Centrosema pubescens and Pueraria phaseoloides were examined. With three sedentary soil types, uptake of molybdenum at a soil pH value of below 5 was sufficiently low to limit plant growth. Application of sodium molybdate at the rate of 1 lb per acre and/or liming the soil to pH 6, increased the molybdenum and nitrogen contents of the plants, and increased dry weight production. It is suggested that the beneficial effect of liming is mainly due to its effect on molybdenum uptake.

Leguminous creepers are used as cover plants in rubber cultivation and the possibility of their growth being limited because of minor element deficiencies in the soil has been discussed in a previous article (WATSON 1957). Molybdenum is one of the minor nutrient elements most likely to be available at only low levels in Malayan soils and there is an unconfirmed report of leguminous cover plants benefiting from the application of sodium molybdate (SANDISON AND HANLEY 1954). The great majority of Malayan soils are acid, with pH values ranging between 4.5 and 5.5, and under these conditions the molybdenum in the soil is held at a very low level of availability (DAVIES 1956). This effect is likely to be accentuated in lateritic soils where the molybdenum will also tend to be held, with iron oxide, in an unavailable form (PRESCOTT AND PENDLETON 1952; MULDER 1954) Molybdenum is of importance in the symbiotic nitrogen fixation process characteristic of legumes (ANDERSON AND THOMAS 1946; ANDERSON 1956), and the pot experiments reported here were carried out to determine to what extent the uptake of molybdenum of leguminous creepers can be affected by soil type and acidity.

EXPERIMENTAL METHOD

Two leguminous creepers commonly grown as cover plants, *Centrosema pubescens* and *Pueraria phaseoloides*, were used in two separate experiments. The experimental treatments were:

Soil Types

Experiment I *(Centrosema pubescens)*
1. Serdang Series, sandy loam
2. Rengam Series, sandy clay loam
3. Selangor Series, alluvial heavy clay

Experiment II *(Pueraria phaseoloides)*
1. Serdang Series, sandy loam
2. Rengam Series, sandy clay loam
3. Selangor Series, alluvial heavy clay
4. Malacca Series, loam

Soil pH Levels (Both Experiments)
1. As received from the field, below pH 5
2. pH 6.0
3. pH 7.0

Molybdate Levels (Both Experiments)
1. No application
2. Sodium molybdate applied at a rate equivalent to 1 lb per acre (0.013 g. $Na_2 MoO_4 2H_2O$ per pot)

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The treatments were applied in duplicate, giving a total of 36 pots for Experiment I and 48 pots for Experiment II.

The soil types used in the two experiments were obtained from the same sites but at different times and the two sets of bulk samples differed somewhat on analysis (Table 1). The results from the two experiments are however grouped together in the tables for convenience. The different pH levels were obtained by mixing slaked lime intimately into the soil in appropriate quantities determined from the lime-titration curves of the soils. Any appreciable decreases in the soil pH values occurring during the course of the experiments were corrected by adding suitable quantities of lime in water suspension.

Large clay pots, painted on the inside with bituminous paint, were filled with approximately 75 lb of soil and limed to the required pH levels. Where necessary, sodium molybdate was applied in solution. Application of fertiliser solution equivalent to dressings of 2 cwt per acre of superphosphate, and 1 cwt per acre each of muriate of potash and magnesium sulphate, were made to all pots in both experiments. No nitrogenous fertilisers were applied. The experimental plants were established from seed inoculated with effective rhizobia (RUBBER RESEARCH INSTITUTE OF MALAYA 1954) and allowed to grow for some 4½ months, in which time several cuts of green material were taken. Analytical results from all samplings were similar and only those from the final sampling are discussed in this paper. At the final sampling all leaf and stem material was cut, and the roots and nodules were collected and washed free from soil. In Experiment I the *Centrosema pubescens* leaf and stem material was analysed as one sample, but in Experiment II the leaf and stem of the *pueraria phaseoloides* samples were analysed separately.

RESULTS

Dry Weight of Material Produced per Pot

The dry weight of leaf and stem produced in both experiments was significantly increased by liming the soil to pH 6, but growth decreased slightly on liming further to pH 7 (Table 2). The weight of nodules produced per pot generally decreased with increasing soil pH. In Experiment II the weight of roots produced also decreased with increasing soil pH, but calculation showed no consistent effect of pH on the weight of nodules produced per unit weight of root.

The weight of leaf, stem and nodules, varied significantly between the different soil types, the greatest quantities being produced in the Selangor Series clay. In Experiment I there was a tendency for more leaf and stem to be produced in the presence than in the absence of molybdate at the lowest pH level, and in Experiment II this effect was statistically significant for all soils except the Selangor Series clay. At the two higher pH levels, the application of molybdate had no significant effect on the weight of plant material produced.

Calcium Content

The calcium content of the leaf, stem and nodules of both plants was increased appreciably by liming to pH 6, with a smaller increase following further liming to pH 7 (Table 3); this effect was more marked with the three sedentary soils than with the alluvial clay. The application of molybdate had no significant effect on the calcium content.

Molybdenum Content

Liming and the application of molybdate both had marked effects on the molybdenum content of leaf, stem and nodules (Table 4). A general linear response to the application of calcium was found, and high levels of molybdenum appeared at pH 7 in both with and without applied molybdate. The application of molybdate significantly increased the molybdenum content of the leaf, stem, and nodules of both plants at all pH levels, although with *Pueraria* the increases were smaller and less consistent in the leaf than in the stem and nodules. At the lowest pH level, and in the absence of applied molybdate, higher quantities of molybdenum were found in the leaf and nodules of the *Pueraria*

than in its stem but, as uptake increased following application of molybdate and/or lime, the position was reversed, much higher levels being found in the stem.

Significant differences in molybdenum uptake by plants growing on the different soil types were recorded. In Experiment I, plants growing in the Rengam Series soil had the highest molybdenum content. In Experiment II, molybdenum uptake from the different soils was more even, but liming, in the absence of applied molybdate, gave a greater increase in molybdenum uptake on Selangor Series clay than on the other soils.

Nitrogen Content

In Experiment I, the nitrogen content of the *Centrosema* leaf, stem, and nodules, was significantly increased by the application of molybdate, and this effect was particularly marked at the lowest pH level; the nitrogen content was also increased by the application of lime (Table 5).

In Experiment II, the application of lime caused a significant increase in the nitrogen content of the leaf and tended to increase that of the nodules. In this experiment, the application of molybdate increased the nitrogen content of leaf, stem and nodules only in the absence of applied lime.

Manganese Content

The results in Table 6 show that the application of lime markedly decreased the leaf and stem content of manganese. In the absence of applied lime, the application of sodium molybdate significantly decreased the leaf and stem content of manganese. In the high pH treatments, only minor differences existed between the manganese contents of the leaf and stem of *Pueraria*, but when grown in soil at field pH, the stem contained much more manganese than did the leaf.

Magnesium, Potassium and Phosphorus Content

No marked treatment effects on the contents of magnesium, potassium and phosphorus were recorded. The application of these elements as fertilisers at the commencement of the experiment probably raised their level of availability in the soil sufficiently to mask any slight treatment effects. The results for magnesium are given in Table 7, since the relative importance of calcium and magnesium in legume and rhizobium nutrition is the subject of discussion (McCalla 1937; Norris 1959).

DISCUSSION

Effect of Soil Type

The soils chosen for the experiments were representative samples of the more important soil types used for rubber cultivation (Owen 1951). The nutrient status, as determined by soil analysis, was similar in each of the three sedentary soils, the Kedah, Rengam and Malacca Series soils, although the ferruginous nature of the Malacca Series loam was reflected in a low silica/sesquioxide ratio. The plants grown on these three soils gave similar responses to treatments. The Selangor Series alluvial clay is a fertile soil with a high nutrient status. Rubber growing on this soil will rarely respond to fertiliser application, and the leguminous creepers grew more vigorously and showed less response to the molybdate application when growing on this soil than on the other three. A surprising feature of plants grown on this soil, bearing in mind its high calcium status, was their more marked response in leaf and stem production to the application of lime. This difference may have been due to an effect of the lime application on the structure and aeration of this fine textured soil—a suggestion which is supported by the observation that the weight of roots in this soil was uniform through the pH range, but fell by 50% over the range pH < 5 to pH 7 in the other soils.

Higher manganese contents were found in plants growing in the Malacca Series soil than in those growing in the Selangor Series soil, although the latter contained a much higher level of exchangeable manganese. Definite conclusions cannot be drawn from the limited soil analytical data available (Table 1) but

this effect may well be related to the much higher exchangeable calcium/exchangeable manganese ratio of the Selangor Series soil (KIPPS 1947; HEWITT 1948)).

The Selangor Series clay contained the highest level of total molybdenum, and in Experiment II higher levels of molybdenum were found in the roots and nodules in this soil, in all treatments, than in the other soils. The low response to molybdate application shown by plants growing in this soil is probably a reflection of its relatively high molybdenum status. In the case of the leaf and stem contents of molybdenum, this superiority of the alluvial clay soil was shown only at the two lower pH levels and in the absence of applied lime. The Selangor Series clay had the highest silica/sesquioxide ratio, while the Malacca Series had the lowest, but molybdenum uptake does not appear to have been related to this factor. A larger number of soils, with a range of silica/sesquioxide ratio values, would need to be used before a definite conclusion on this point could be drawn.

Effect of Lime and Molybdate Treatments

The major effects of the lime treatments on the plant nutrient status were marked increases in the calcium and molybdenum contents and sharp decreases in the manganese content of the leaf and stem; these particular responses were very marked but growth responses were not correspondingly high. The most important growth response, occurring in both experiments, was an increase in leaf and stem production caused by liming up to pH 6. With the three sedentary soils, further liming to pH 7 caused a slight decrease in dry weight production compared with that at pH 6, although at the same time the leaf molybdenum and calcium contents were further increased. The weight of nodules produced per pot generally decreased with increasing soil pH, and in Experiment II the weight of roots decreased also. If the nitrogen content of the increased amount of green material had been produced solely by increased nitrogen fixation it might have been thought that the efficiency of nodule activity had been increased, but liming will also have affected the mineralisation of the soil organic nitrogen (GUHA AND WATSON 1957) and so no definite conclusion can be reached on this point.

The application of molybdate to the soil increased the molybdenum content of all materials at all pH levels and decreased the manganese content at the lowest pH level. In both experiments the application of lime tended to increase the nitrogen content of leaf, stem and nodule material but the application of molybdate increased the nitrogen content at the lowest pH level only. At this pH level, where the plants contained only low levels of molybdenum, the nitrogen content of the leaf and nodule material from both experiments was significantly correlated with the molybdenum content, both in the presence ($r = 0.79$, significant at 0.01% level) and absence ($r = 0.80$, significant at 0.01% level) of applied molybdate. Molybdenum is known to play a particularly important role in the nitrogen metabolism of legumes, and this correlation suggests that at the lowest pH level the molybdenum content of the test plants was at a low enough level to limit nitrogen fixation. The molybdenum content of plants growing in the absence of applied lime or molybdate was very low indeed and application of molybdate to the soil increased both the molybdenum content and nitrogen content of the plants. Liming of the soil to pH 6 caused rather greater increases in both the molybdenum and nitrogen contents, while the application of both lime and molybdate gave a slight further increase on average. Liming to pH 7 increased the molybdenum content even further but gave no increase in nitrogen content, and molybdenum uptake at this pH level could well have been in excess of the plants' requirements.

Because of the effect of lime in increasing molybdenum uptake it is not possible from these experiments to determine the direct effect of the lime applications. Since there was a definite beneficial effect from the application of molybdate in the absence of liming, it seems possible that the benefit conferred

by the application of lime at the first level was mainly due to its effect in increasing the availability of molybdenum in the soil. This would conform with the opinion that legumes indigenous to the humid tropics do not have a high calcium requirement (NORRIS 1956, 1959), and that reported benefits from liming (e.g. LANDRAU *et al.* 1953 SAMUELS and LANDRAU 1953) are more probably due to a release of other limiting nutrients within the soil than to a direct effect of the calcium. The beneficial effect of basic slag on the growth of *C. pubescens* reported by HAMILTON AND PILLAY (1941) may also, in a similar manner, have been due to an effect of basic slag on the minor element nutrition of the plants, as the authors suggested. NORRIS (1959) states that the root nodule bacteria associated with tropical legumes have a greater requirement for magnesium than for calcium. The magnesium status of the test plants was not affected by the lime or molybdate treatments in any general manner, and it must be presumed that this element was sufficiently available for the needs of both the plant and bacteria at all pH levels. The beneficial effect of the lime applications observed in these experiments cannot have been due to the depression of the high manganese uptake observed at the lowest pH level, for such an uptake of manganese is normal for the test plants in their natural environment, and in any case the application of molybdate at the lowest pH level increased the growth and nitrogen content of the plants while decreasing the manganese level to only a small extent.

It can be concluded that, under the conditions of this experiment, the uptake of molybdenum by *Pueraria phaseoloides* and *Centrosema pubescens* when growing in the sedentary Kedah Series, Rengam Series and Malacca Series soils at field pH level was at a growth-limiting level. An increase in available molybdenum in these soils, caused by application of either sodium molybdate or lime, increased both the molybdenum and nitrogen content of the plants and there was a tendency for increases in dry weight production to occur at the same time. The Selangor Series alluvial clay had a higher content of available molybdenum than the sedentary soils and uptake of the element at field pH was adequate for plant growth. The conclusion should not be drawn from these experiments that the normal leguminous cover will generally respond to applications of either lime or sodium molybdate. However, some indication is given of the availability of applied molybdate, should such an application be thought necessary in cases of suspected molybdenum deficiency. For experimental purposes the results show the importance of considering molybdenum uptake by the plant when carrying out liming trials with legumes.

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TABLE 1. SOIL ANALYSIS

Soil	Experiment	pH	Carbon %	Total nitrogen %	Exchangeable cations (m.equiv. per 100 g soil)			$\frac{SiO_2}{R_2O_3}$ (1)	Exch. Mn p.p.m.	Total Mo (2) p.p.m.
					Ca	Mg	K			
Kedah Series,	I	4.37	0.51	0.065	0.14	0.01	0.03	—	—	—
sandy loam	II	4.98	1.12	0.103	0.16	0.08	0.07	0.95	1.2	0.92
Rengam Series,	I	4.74	0.45	0.052	0.24	0.05	0.07	—	—	—
sandy clay loam	II	4.99	1.10	0.111	0.61	0.26	0.17	0.84	—	1.23
Selangor Series,	I	4.35	0.89	0.110	3.23	7.28	0.32	—	—	—
alluvial clay	II	4.70	1.66	0.195	2.02	1.94	0.48	1.37	11.1	3.84
Malacca Series,	I	—	—	—	—	—	—	—	—	—
loam	II	5.00	1.28	0.099	0.07	0.08	0.01	0.46	3.8	1.08

(1) Determined on ignited clay (2) Determined in 5:3 HCl soil extract

TABLE 2. DRY WEIGHTS OF MATERIAL PRODUCED IN GRAMS PER POT

Experiment	Material	Soil pH	Soil Series								Mean	s.e.
			Kedah		Rengam		Selangor		Malacca			
			Molybdate level									
			0	1	0	1	0	1	0	1		
I (*Centrosema pubescens*)	Leaf and stem (all samplings)	< 5	10.3	14.3	27.6	42.8	118.5	127.7			56.9	
		6	15.8	46.4	58.9	39.6	183.7	178.5			87.2	± 4.6368
		7	29.4	10.9	38.3	16.4	187.3	179.2			76.9	
		Mean	18.5	23.9	41.6	32.9	163.2	161.8				
		s.e.	± 6.5038									
	Nodules	< 5	1.34	1.06	2.63	2.29	2.66	3.86			2.31	
		6	1.25	1.94	3.49	2.30	2.35	2.28			2.27	± 0.277
		7	1.40	0.47	2.66	1.00	1.39	1.28			1.37	
		Mean	1.33	1.16	2.93	1.86	2.13	2.47				
		s.e.	± 0.391									
II (*Pueraria phaseoloides*)	Leaf and stem (all samplings)	< 5	86.6	119.7	124.7	139.0	144.3	131.8	76.3	92.6	114.4	
		6	134.3	133.6	160.8	151.4	180.0	159.6	127.1	127.2	146.8	± 2.645
		7	103.5	128.2	115.3	121.0	202.7	209.5	114.7	112.8	138.5	
		Mean	108.1	127.2	133.6	137.1	175.7	167.0	106.0	110.9		
		s.e.	± 4.319									
	Roots	< 5	33.6	39.8	35.5	35.0	30.2	27.2	36.0	41.5	34.9	
		6	39.2	35.5	35.0	34.5	30.2	33.3	36.5	34.5	34.8	± 1.0656
		7	15.6	24.3	18.0	21.5	28.3	32.8	23.0	19.5	22.9	
		Mean	29.5	33.2	29.5	30.3	29.6	31.1	31.8	31.8		
		s.e.	± 1.7401									
	Nodules	< 5	4.04	4.12	6.24	4.80	4.49	3.83	5.26	3.58	4.55	
		6	4.41	2.63	4.13	4.82	3.58	4.63	2.46	3.23	3.74	± 0.2871
		7	2.36	4.31	3.12	1.99	5.09	6.12	2.38	2.40	3.47	
		Mean	3.60	3.69	4.50	3.87	4.39	4.86	3.37	3.07		
		s.e.	± 0.4688									

TABLE 3. PERCENTAGE CALCIUM IN LEAF, STEM AND NODULES

Experiment	Material	Soil pH	Soil Series								Mean	s.e.
			Kedah		Rengam		Selangor		Malacca			
			Molybdate level									
			0	1	0	1	0	1	0	1		
I (*Centrosema pubescens*)	Leaf and stem	< 5	0.17	0.13	0.20	0.25	0.35	0.26			0.23	
		6	1.50	1.27	1.67	1.65	1.18	1.20			1.41	± 0.043
		7	1.32	1.55	1.82	2.06	1.39	1.13			1.55	
		Mean	1.00	0.98	1.23	1.32	0.97	0.86				
		s.e.	± 0.0608									
II (*Pueraria phaseoloides*)	Leaf	< 5	0.28	0.25	0.51	0.43	0.33	0.32	0.25	0.18	0.32	
		6	1.46	1.58	1.24	1.18	1.07	1.09	1.21	1.07	1.24	± 0.0265
		7	1.64	1.75	1.47	1.52	1.29	1.20	1.72	1.60	1.52	
		Mean	1.13	1.19	1.07	1.04	0.90	0.87	1.06	0.95		
		s.e.	± 0.0433									
	Stem	< 5	0.38	0.32	0.68	0.54	0.40	0.38	0.28	0.23	0.40	
		6	1.86	1.99	1.53	1.61	1.42	1.42	1.55	1.47	1.61	± 0.0275
		7	2.69	2.43	2.18	2.37	1.62	1.51	2.18	2.07	2.13	
		Mean	1.64	1.58	1.46	1.51	1.15	1.10	1.34	1.26		
		s.e.	± 0.0449									
	Nodules	< 5	0.10	0.10	0.19	0.16	0.10	0.10	0.05	0.07	0.11	
		6	0.94	1.12	0.75	0.70	0.67	0.63	0.62	0.46	0.74	± 0.0368
		7	1.23	1.59	1.10	1.01	0.75	0.70	0.75	0.54	0.96	
		Mean	0.76	0.94	0.68	0.62	0.51	0.48	0.47	0.36		
		s.e.	± 0.0060									

TABLE 4. MOLYBDENUM IN LEAF, STEM AND NODULES, P.P.M.

Experiment	Material	Soil pH	Soil Series								Mean	s.e.
			Kedah		Rengam		Selangor		Malacca			
			Molybdate level									
			0	1	0	1	0	1	0	1		
I (*Centrosema pubescens*)	Leaf and stem	< 5	0.12	0.94	0.07	1.19	0.10	0.93			0.56	
		6	3.03	11.74	3.30	37.96	1.34	15.92			12.22	*
		7	1.30	17.04	4.29	89.37	2.24	15.84			21.68	
		Mean	1.48	9.91	2.55	42.84	1.23	10.90				
		s.e.	*									
	Nodules	< 5	0.40	4.96	0.74	4.17	2.02	3.70			2.67	
		6	9.47	13.19	3.93	15.38	3.32	6.25			8.59	± 0.6583
		7	5.54	16.87	7.20	31.40	6.54	10.51			13.01	
		Mean	5.14	11.67	3.96	16.98	3.96	6.82				
		s.e.	± 0.9382									
II (*Pueraria phaseoloides*)	Leaf	< 5	0.33	0.18	0.43	0.46	0.95	0.94	0.74	1.11	0.64	
		6	0.21	0.94	0.71	0.96	1.76	2.68	0.68	0.60	1.07	± 0.3789
		7	0.38	1.26	0.98	5.20	4.62	1.35	0.98	2.61	2.17	
		Mean	0.31	0.79	0.71	2.21	2.44	1.66	0.80	1.44		
		s.e.	± 0.6187									
	Stem	< 5	0.06	3.25	0.04	1.30	0.86	2.18	0.02	2.16	1.23	
		6	0.10	9.56	0.69	6.78	4.27	8.61	0.15	2.46	4.08	*
		7	2.29	15.65	8.00	27.96	19.95	26.71	6.05	31.43	17.26	
		Mean	0.82	9.49	2.91	12.01	8.36	12.50	2.07	12.02		
		s.e.	±									
	Nodules	< 5	0.33	2.48	0.73	1.31	2.72	3.28	0.16	0.77	1.47	
		6	0.67	2.48	0.64	1.93	5.65	5.23	0.81	1.69	2.39	± 0.1880
		7	1.60	4.26	2.47	4.17	10.60	10.54	1.54	2.94	4.77	
		Mean	0.87	3.07	1.28	2.47	6.32	6.35	0.84	1.80		
		s.e.	± 0.3069									
	Roots	< 5	0.03	0.91	0.08	0.83	0.30	1.52	0.02	0.11	0.48	
		6	0.03	0.95	0.14	1.09	0.69	2.37	0.01	0.28	0.70	
		7	0.13	1.02	0.28	3.79	1.87	8.04	0.14	0.51	1.97	
		Mean	0.06	0.96	0.17	1.90	0.95	3.98	0.06	0.30		
		s.e.	*									

* s.e. not calculated because of large variation in treatment means.

TABLE 5. PERCENTAGE NITROGEN IN LEAF, STEM AND NODULES.

Experiment	Material	Soil pH	Soil Series								Mean	s.e.
			Kedah		Rengam		Selangor		Malacca			
			Molybdate level									
			0	1	0	1	0	1	0	1		
I (*Centrosema pubescens*)	Leaf and stem	< 5	2.15	3.25	2.60	3.08	2.74	2.88			2.78	
		6	3.23	3.27	2.88	2.87	2.76	2.84			2.98	± 0.067
		7	3.00	3.61	2.66	2.35	2.77	2.78			2.86	
		Mean	2.79	3.38	2.71	2.77	2.76	2.83				
		s.e.	± 0.0946									
	Nodules	< 5	3.30	4.65	3.57	4.26	4.77	5.30			4.31	
		6	4.35	4.48	4.06	4.12	4.65	5.01			4.45	± 0.0707
		7	4.24	4.85	4.35	3.98	4.92	5.02			4.56	
		Mean	3.96	4.66	3.99	4.12	4.78	5.11				
		s.e.	± 0.0999									
II (*Pueraria phaseoloides*)	Leaf	< 5	2.53	2.46	3.07	3.42	3.75	3.78	2.72	3.02	3.09	
		6	3.42	3.53	3.86	3.86	3.34	3.50	3.70	3.64	3.61	± 0.0606
		7	3.74	3.37	4.31	4.42	3.56	3.65	3.17	3.20	3.68	
		Mean	3.23	3.12	3.75	3.90	3.55	3.64	3.20	3.29		
		s.e.	± 0.099									
	Stem	< 5	0.95	1.08	1.05	1.24	1.47	1.49	0.96	1.14	1.17	
		6	1.27	1.27	1.53	1.61	1.30	1.48	1.55	1.46	1.43	± 0.0309
		7	1.55	1.29	1.73	1.82	1.44	1.39	1.27	1.16	1.46	
		Mean	1.26	1.21	1.44	1.56	1.40	1.45	1.26	1.25		
		s.e.	± 0.0504									
	Nodules	< 5	3.47	4.22	3.94	4.03	4.40	4.53	3.47	4.00	4.01	
		6	3.79	4.04	4.46	4.05	4.59	4.33	4.74	4.68	4.34	± 0.1019
		7	3.57	3.82	4.55	4.65	4.77	4.47	4.09	4.52	4.31	
		Mean	3.61	4.03	4.32	4.24	4.59	4.44	4.10	4.40		
		s.e.	± 0.1662									

TABLE 6. MANGANESE IN LEAF, STEM AND NODULES, P.P.M.

Experiment	Material	Soil pH	Soil Series								Mean	s.e.
			Kedah		Rengam		Selangor		Malacca			
			Molybdate level									
			0	1	0	1	0	1	0	1		
I (*Centrosema pubescens*)	Leaf and stem	< 5	63	47	95	81	206	185			113	
		6	16	9	14	15	83	74			35	± 2.408
		7	13	7	15	17	77	82			35	
		Mean	31	21	41	38	122	114				
		s.e.	± 3.405									
	Leaf	< 5	87	68	70	68	87	81	119	70	81	
		6	72	69	42	48	79	90	111	107	77	± 3.057
		7	37	41	28	24	56	45	55	44	41	
		Mean	65	59	47	47	74	72	95	74		
		s.e.	± 4.992									
II (*Pueraria phaseoloides*)	Stem	< 5	525	307	297	264	489	494	1438	1176	624	
		6	60	42	18	23	76	109	138	163	79	*
		7	15	17	12	10	28	23	27	22	19	
		Mean	200	122	109	99	198	209	534	454		
		s.e.	*									
	Nodules	< 5	13	16	15	26	22	18	50	45	26	
		6	16	11	7	18	19	17	26	31	18	± 2.717
		7	13	9	16	16	11	17	64	28	22	
		Mean	14	12	13	20	17	17	47	35		
		s.e.	± 4.436									

* s.e. not calculated because of large treatment variations.

TABLE 7 PERCENTAGE MAGNESIUM IN LEAF, STEM AND NODULES.

Experiment	Material	Soil pH	Soil Series								Mean	s.e.
			Kedah		Rengam		Selangor		Malacca			
			Molybdate level									
			0	1	0	1	0	1	0	1		
I (*Centrosema pubescens*)	Leaf and stem	< 5	0.16	0.14	0.12	0.12	0.21	0.21			0.16	
		6	0.11	0.12	0.14	0.15	0.23	0.23			0.16	±0.0044
		7	0.10	0.12	0.14	0.15	0.25	0.23			0.17	
		Mean	0.12	0.13	0.13	0.14	0.23	0.23				
		s.e.	± 0.0062									
II (*Pueraria phaseoloides*)	Leaf	< 5	0.43	0.34	0.40	0.37	0.37	0.36	0.45	0.33	0.38	
		6	0.29	0.34	0.33	0.32	0.30	0.30	0.29	0.29	0.31	±0.00572
		7	0.30	0.32	0.33	0.33	0.31	0.31	0.33	0.34	0.32	
		Mean	0.34	0.33	0.35	0.34	0.33	0.32	0.36	0.32		
		s.e.	± 0.0107									
	Stem	< 5	0.23	0.19	0.21	0.24	0.20	0.20	0.24	0.19	0.21	
		6	0.22	0.19	0.19	0.19	0.15	0.16	0.17	0.15	0.18	±0.00397
		7	0.22	0.22	0.21	0.22	0.18	0.19	0.20	0.21	0.21	
		Mean	0.22	0.20	0.20	0.22	0.18	0.18	0.20	0.18		
		s.e.	± 0.0065									
	Nodules	< 5	0.20	0.19	0.24	0.21	0.30	0.29	0.21	0.24	0.24	
		6	0.22	0.25	0.25	0.21	0.35	0.29	0.41	0.33	0.29	±0.0149
		7	0.28	0.22	0.32	0.35	0.31	0.28	0.28	0.24	0.29	
		Mean	0.23	0.22	0.27	0.26	0.32	0.29	0.30	0.27		
		s.e	± 0.0243									

A Comparison of Rock Phosphate and Superphosphate As Sources of Phosphorus for Seedling Rubber

K. R. MIDDLETON

Rock phosphate was compared with superhosphate as a source of phosphorus for rubber seedlings in a pot experiment using a latosolic, phosphate-deficient soil. Three different methods of applying the fertilisers were also compared. It was found that superphosphate, when put into pockets in the soil, gave larger and heavier plants than any other treatment, but when mixed with soil or broadcast, as in normal plantation practice, gave results similar to those obtained with rock phosphate. Liming was found to depress the response to rock phosphate, irrespective of method of application, but with superphosphate it produced no definite effect. The soil proved capable of 'fixing' large amounts of applied phosphate, so that after ten months more than 90% of the added fertilisers had been made unavailable for the growth of rubber seedlings.

As a source of phosphorus for rubber trees in Malaya, rock phosphate is generally considered to be as effective as superphosphate and the main reasons for this opinion have already been given elsewhere (RUBBER RESEARCH INSTITUTE OF MALAYA 1959). This is not the experience with most crops in other countries where the superiority of superphosphate is usually found to be sufficient to offset its considerably greater cost (ROGERS *et al.* 1953). A partial explanation for the anomaly may be the ability of *Hevea brasiliensis* to thrive in strongly acid soils. Such soils occur in most Malayan plantations and they impose conditions which are thought to increase the solubility of rock phosphate and to decrease the availability of superphosphate (RUBBER RESEARCH INSTITUTE OF MALAYA 1959). It has been suggested that the differential effect of acid soil on the two fertilisers might be modified by applying them in different ways: a field trial to test this on Bujong Estate in 1953 did in fact show some differences between the two, depending on whether the phosphates were mixed with soil in the planting-hole (RUBBER RESEARCH INSTITUTE OF MALAYA 1958), broadcast on the surface or placed in bands two inches below the surface.

In the pot experiment described here, rock phosphate and superphosphate were compared under carefully controlled conditions, using different methods of application with the object of finding an explanation for the anomalous behaviour of superphosphate mentioned above. A further aim of the experiment was to provide information which would be helpful in designing new field trials on methods of applying the two fertilisers. It is generally accepted that conclusions drawn from pot experiments are difficult to relate to field conditions. For this reason large pots were used and filled with a soil type widely used for rubber cultivation in Malaya. In order to simulate as closely as possible the conditions in the planting-hole in which seedlings are planted in the field, no sand was mixed with the soil.

EXPERIMENTAL METHOD

Soil for the experiment was taken from Field 19 at the R.R.I.M. Experiment Station; it has been classified by OWEN (1951) as belonging to the Kedah Series. It is an acidic, red, sandy soil with little organic matter and few exchangeable bases, and *in situ* its drainage is free but not excessive. In pot experiments, sand is usually mixed with the soil in order

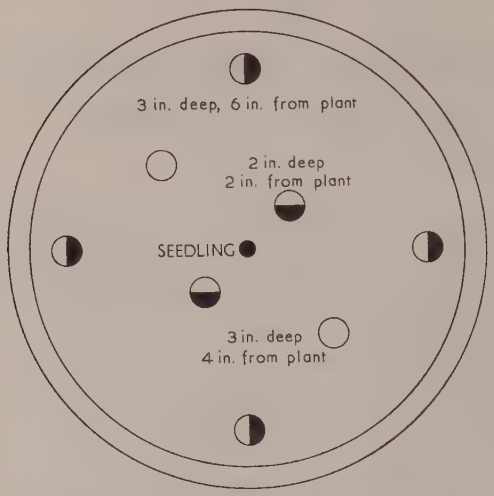

Figure 1. Arrangements of pockets for applying fertilisers to rubber seedlings.

to avoid difficulties with aeration and drainage, but although sand was omitted in this experiment no such difficulties arose, probably because a soil with an open texture had been chosen.

Carefully selected clonal seeds (Tjirandji 1 — self pollinated) were germinated in sand and the more vigorous plants transplanted into pots.

The phosphatic fertilisers used were Christmas Island rock phosphate containing about 38% total and 11% citric-soluble P_2O_5, and superphosphate containing 40% P_2O_5, the latter in two forms: the granulated commercial product and a powder similar in particle-size to rock phosphate (90% of which passes a 100 mesh I.M.M. Sieve). Large earthenware pots, painted inside with bituminous paint, were filled with 73 lb of soil, the surface of which was covered with a shallow layer of coarse, acid-washed sand. This was added in order to prevent puddling of the soil surface by watering and was also found to control effectively the development of moulds and algae.

Treatments

One ounce of either rock phosphate or superphosphate was applied to the soil in all pots except the untreated controls. Three different methods of applying the phosphates were employed, namely: broadcasting on the surface, uniform mixing with the top 4 inches of soil (33 lb) and pocketing in eight symmetrically arranged positions around the centrally placed seedling, as shown in Figure 1. In addition each treatment was repeated using soil in which the original pH of about 4.5 had been adjusted by liming to pH 6. As shown in Figure 2, this gives a total of 20 treatments which were replicated 5 times giving a total of 100 pots; these were arranged in a random order on concrete benches in an open enclosure.

Supplementary Treatment

Supplementary fertilisers were applied twice per month at the rate of one litre per pot of a solution containing 1.8 g $(NH_4)_2SO_4$, 0.2 g KCl and 0.82 g $MgSO_4.7H_2O$. The plants were watered every other day in the absence of rain or of the above supplement. After three months' growth, magnesium deficiency symptoms developed in many plants and the amount of $MgSO_4$ was doubled for

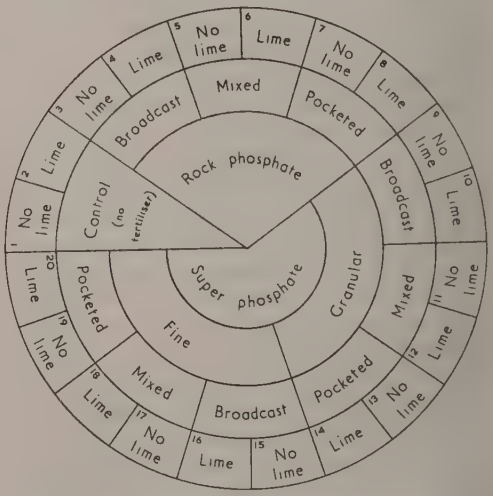

Figure 2. Fertiliser treatments used to compare the effect of rock phosphate and superphosphate on the growth of rubber seedlings.

the duration of the experiment. The plants also received the micro-nutrient supplement recommended by HEWITT (1952) at the rate of 1.0 ml per litre of the above solution. Later this was increased to 2.5 ml following the appearance, separately, of suspected iron, manganese and copper deficiency symptoms in various plants.

After three and a half months a number of plants were severely attacked by thrips and thereafter all plants were sprayed with dieldrin (1: 800 parts of water) once a fortnight as a protective measure.

Measurements

Height measurements were taken monthly during the experiment and, at various stages of growth, girth measurements of stems and estimates of leaf area were made; the latter by making sun prints on photosensitive paper

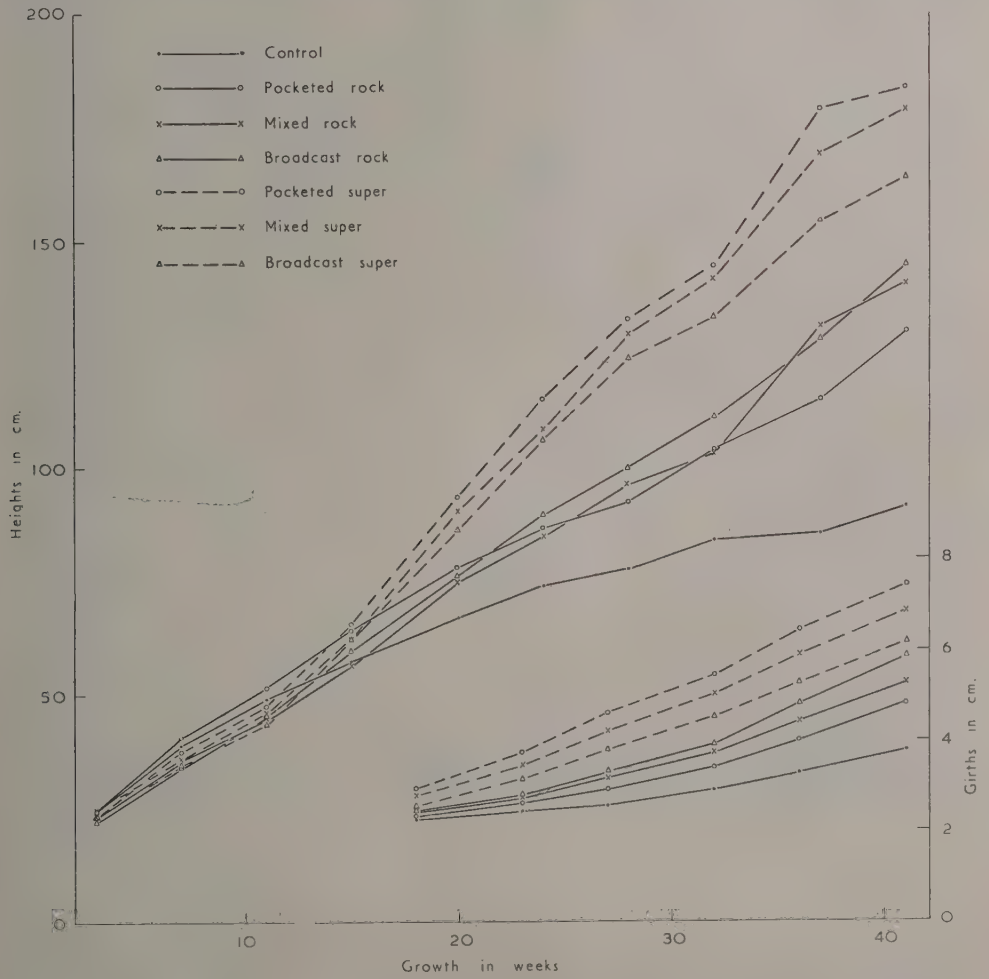

Figure 3. Growth-rate curves for rubber seedlings fertilised with rock phosphate and superphosphate. Growth measured in terms of plant height and girth.

Figure 4. Effect of phosphate treatments on size of tap roots of rubber seedlings
C = control R = rock phosphate S = superphosphate F = fine G = granular
O = no lime L = lime P = pocketed M = mixed B = broadcast
(see page 145).

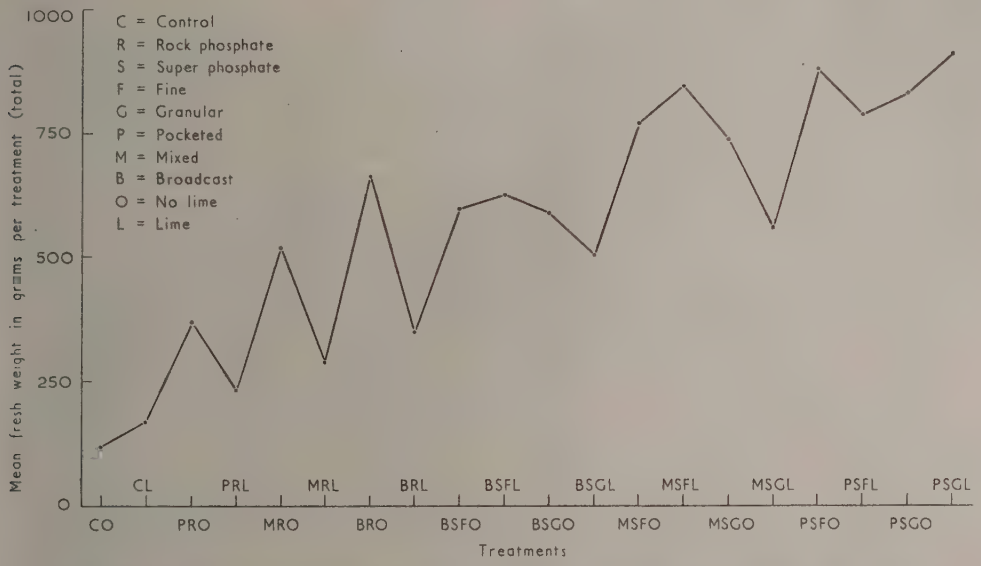

Figure 5. Total fresh weight in grams of rubber seedlings, ten months after being treated with phosphates in the presence and absence of lime.

of a characteristic whorl of leaves from each plant, the areas being obtained by multiplying the weights of the prints by a gravimetric factor. After ten months, many plants, particularly those growing vigorously, started to develop phosphate deficiency symptoms and it was clear that insufficient phosphate had been added for a year's growth as planned. The experiment was therefore terminated, the plants removed from the pots and their roots washed clear of soil with water; measurements were then made of total fresh weight, total dry weight and the dry weight of various vegetative parts, which were also analysed chemically for N, P, K, Ca and Mg.

The average growth rates (putting treatments with and without lime together) are summarised in Figure 3. Measurements of total fresh weight of the plants for the various treatments are shown in Figure 5. Total dry weights and dry weights of the roots and aerial parts when plotted gave closely similar patterns; the somewhat different patterns obtained when leaf area, girth and height of the plants were plotted are shown for comparison in Figure 6. A statistical analysis of the fresh weight data is given in Table 1.

Soil acidity was measured at the beginning of the experiment, when the unlimed pots were found to average pH 4.5 and the limed pots about pH 6.0. Ten months later all pH figures were found to be between 4 and 4.5 with no apparent differences between limed and unlimed treatments. The available phosphate in the soil originally, measured by BRAY AND KURTZ'S method (1945), was found to be 6 p.p.m. P_2O_5 and according to OWEN (1952) such a soil is definitely deficient in phosphate under Malayan conditions.

The results of the chemical analysis of the plants after wet 'ashing' as described by BOLLE-JONES (1954a), are summarised in Table 2.

RESULTS AND DISCUSSION

An examination of the growth-rate curves in Figure 3, shows that the different fertiliser treatments had not influenced the plants appreciably until about eighteen weeks had

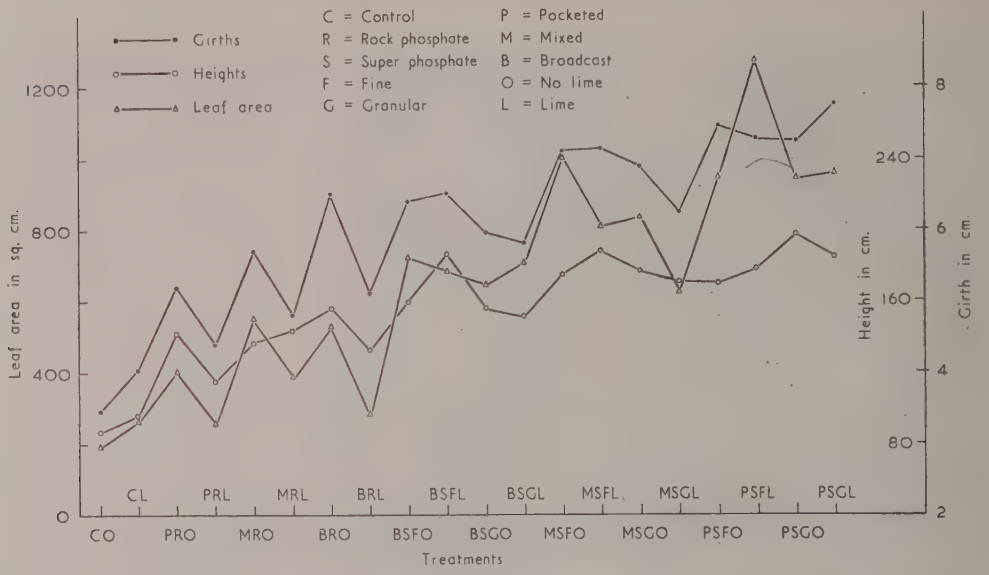

Figure 6. Heights, girths and leaf-areas of rubber seedlings after treatment with phosphates.

elapsed. That the rubber plant is not dependent on external supplies of nutrients for a considerable time after germination has been noted in earlier experiments by SHORROCKS (1958); at this early stage the plant is able to draw on the large food reserve present in the seed. It will also be noted that there is a more regular increase in girth than in height. Figures 5 and 6 show that girth is also a better indication of the total fresh weight of the plant than either height or leaf area. The curves in Figure 3 show that the growth of the plants (in terms of height and girth) had not been seriously interrupted before the end of the experiment. This is considered to justify the discussion and conclusions which follow, although, as previously mentioned, phosphate deficiency symptoms had appeared generally among the plants before the experiment was terminated.

Effect of Treatments on Fresh Weight

A study of Figure 5, which shows the average fresh weight of five plants for each of the twenty treatments, indicates a number of interesting results, only some of which attain statistical significance as will be shown later.

Rock phosphate. There is a well-marked response to rock phosphate in the absence of lime, this is greatest for the broadcast method of application and least for the pocketing method. The greater accessibility to plant roots of the fertiliser when broadcast or mixed suggests that these two treatments should be better than pocketing, but this explanation fails to account for the apparent superiority of broadcasting over mixing, which is an unexpected result (RUBBER RESEARCH INSTITUTE OF MALAYA 1956).

When lime is added, the response to rock phosphate is almost completely suppressed for all methods of application, although lime on its own has a small positive effect. The presence of lime might be expected to reduce the solubility of rock phosphate, which is more soluble in acid solutions, and this appears a reasonable explanation for the

suppression of the phosphate response. A similar effect for root crops was found by Cooke (1957) who concluded that rock phosphate was about two-thirds as effective as superphosphate on very acid soils in Britain, but far less effective on neutral soils; Fried and Mackenzie (1949), who carried out pot experiments on grass and legumes, came to a similar conclusion. The effect of lime and the effect of different methods of applying rock phosphate are clearly shown in Figure 7 which is a photograph taken after 10 months' growth.

Superphosphate. Figure 5 also shows that the response to superphosphate is in general greater than to rock phosphate, but the order of efficiency of the different methods of applying the fertiliser is reversed, i.e. pocketing is the best and broadcasting the worst, with mixing intermediate. Owen (1947a and 1953) has demonstrated that in the type of soil used in this experiment the availability of superphosphate is reduced by the fixation of phosphate as compounds of iron and aluminium, and it seems reasonable to suppose that fixation should be least when the fertiliser is placed in pockets. This may explain why, in spite of the reduced accessibility to plant roots, the pocketing method is the best for superphosphate.

The effect of lime when superphosphate is used is not as pronounced as with rock phosphate and a suppression of the response to the fertiliser is obtained only in certain cases, notably when granular superphosphate is broadcast or mixed; for these two methods of application there is however no indication of a suppression when the fine fertiliser is used. There is thus an indication that in the presence of lime fine-grained superphosphate is more effective than the granular material, but it has not been possible to establish this statistically.

Visual Assessment of the Plants

The larger size of plants receiving superphosphate compared with those receiving rock phosphate may be seen in Figure 7, A, B and C, which are photographs taken at the end of the experiment when the plants had completed ten months' growth. Figure 7D, which is a photograph after six months' growth, shows that the superiority of superphosphate and the suppression by lime of the rock phosphate response became evident at an early stage in the experiment. The effect of the various treatments upon the tap roots of the plants are shown in Figure 4 and it is interesting to note that when the treatments are arranged in the same order, a pattern of response similar to that shown in Figure 5 is formed.

Statistical Analysis of the Weight Data

The data for leaf area, total dry weight, weight of aerial parts, weight of roots and total fresh weight were statistically analysed. Since the results obtained for all the different sets of measurements were similar, only those for total fresh weight are considered in this paper. The analysis of variance is not given but it should be recorded that the coefficients of variation (single plant) for the various treatments are of the order of 40%.

The variability between replicates was high throughout and higher in treatments containing large plants than in treatments containing small ones. To reduce this heterogeneity of variance within treatments, a logarithmic transformation was carried out on the observed values; Table 1 gives the arithmetic treatment means, the logarithms to the base 10 of the geometric treatment means and the effects determined from the logarithms. The values in brackets were obtained from four pot treatments, the others from five pots. The coefficients of variation for the logarithmic variables were about 10%.

Phosphate in the absence of lime. All nine phosphate treatments gave significant positive responses. For broadcast application, rock phosphate was about as good as granular or fine superphosphate. Mixing and pocketing superphosphate gave numerically better results than broadcasting rock phosphate, while mixing rock phosphate gave inferior results, but none of these comparisons are significant at the 5% level. Pocketing rock phosphate is

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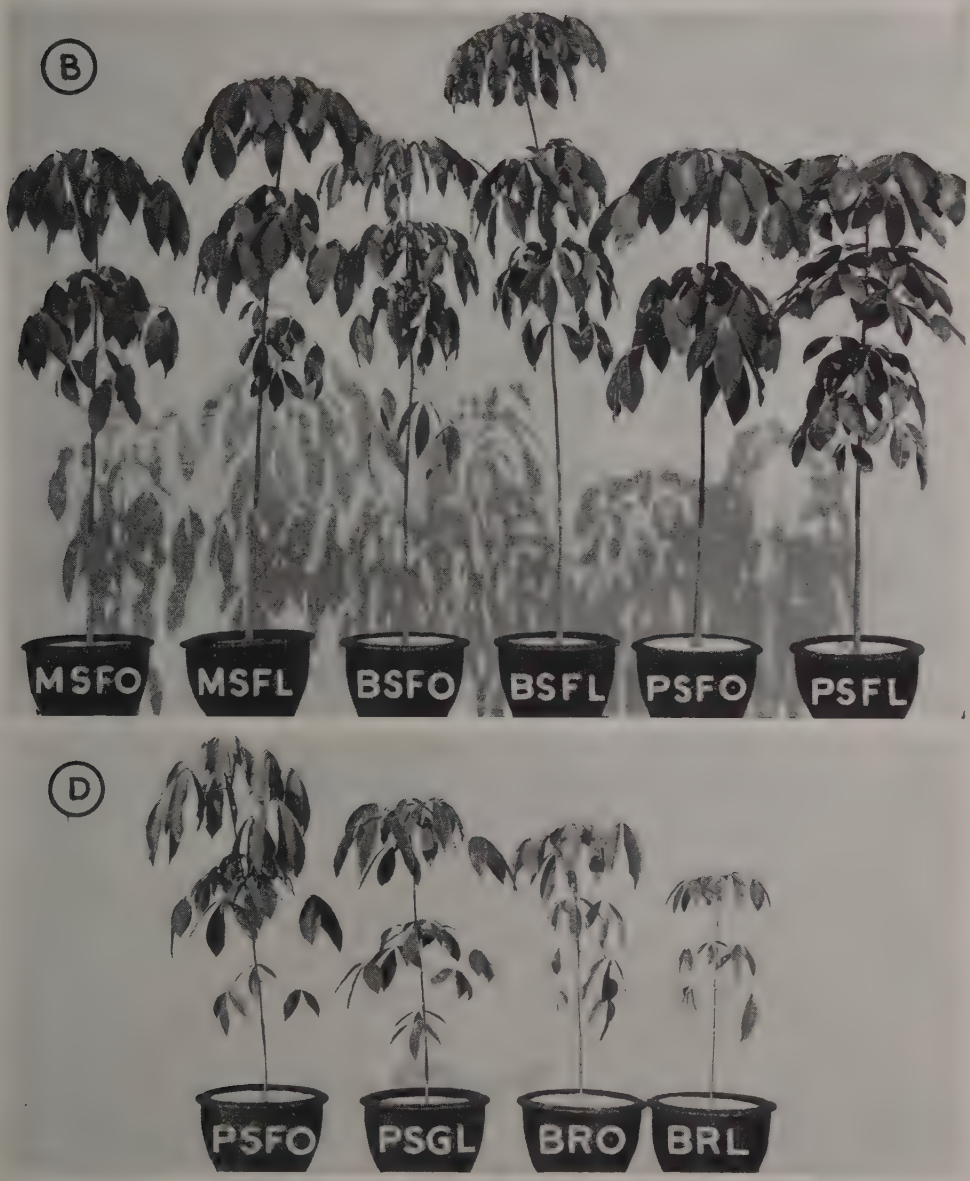

Figure 7. Rock phosphate and superphosphate treatments. A. Rock phosphate treatments: effect of different methods of application and of suppression due to lime. B. Superphosphate treatments: effect of different methods of application (no suppression due to lime). C. Comparison of rock phosphate and superphosphate plants after ten months' growth. D. Comparison of rock phosphate and superphosphate plants after six months' growth.
C = control R = rock phosphate S = superphosphate F = fine G = granular
O = no lime L = lime P = pocketed M = mixed B = broadcast

TABLE 1. EFFECT OF FERTILISER TREATMENTS ON FRESH WEIGHT OF RUBBER SEEDLINGS.

SUMMARY OF STATISTICAL ANALYSIS.

Method of application	Control		Rock phosphate		Granular superphosphate		Fine superphosphate	
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime
Arithmetic means in grams of the fresh weight of five plants								
Pocketed	120†	173†	371	235	834	914	881	794
Mixed			521	291	(742)	560	771	846
Broadcast			663	350	589	505	598	(626)
Logarithms to the base 10 of geometric means of replicates								
Pocketed	2.060†	2.202†	2.531	2.363	2.911	2.956	2.921	2.890
Mixed			2.657	2.381	(2.844)	2.709	2.878	2.905
Broadcast			2.775	2.466	2.744	2.589	2.767	(2.790)
Effect of phosphate calculated from logarithmic variables								
Pocketed			+ 0.471***	+ 0.161	+ 0.851 ***	+ 0.754***	+ 0.861***	+ 0.688 ***
Mixed			+ 0.597***	+ 0.179	(+ 0.784)***	+ 0.507***	+ 0.818***	+ 0.703 ***
Broadcast			+ 0.715***	+ 0.264*	+ 0.684 ***	+ 0.387**	+ 0.707***	(+ 0.588)***
Effect of lime calculated from logarithmic variables								
Pocketed		+ 0.142†		− 0.168		+ 0.045		− 0.031
Mixed				− 0.276*		(− 0.135)		+ 0.027
Broadcast				− 0.309*		− 0.155		(+ 0.023)

Errors of treatment means and effects for logarithmic variables

All figures in brackets represent 4 plants only

s.e. of a treatment mean of 4 plants = ± 0.097; s.e. of a treatment mean of 5 plants = ± 0.087

minimum 5% significant difference between 2 means, one of 5 and the other of 4 plants = 0.260

minimum 5% significant difference between 2 means each of 5 plants = 0.245

s.e. of effects in brackets = ± 0.131; minimum 5% significance level = ± 0.260

s.e. of all other effects = ± 0.123; minimum 5% significance level = ± 0.245

* significant at 5%, ** significant at 1%, *** significant at 0.1% level; † there are no methods of application for controls

however established as inferior to broadcasting rock phosphate and to all the superphosphate treatments except broadcasting the granular material.

Phosphate in the presence of lime. Seven out of the nine phosphate treatments gave significant positive responses. For rock phosphate, only the response to the broadcast method of application is proved statistically; the apparent differences between the three methods of application are not shown to be significant. For superphosphate, significant, positive response were obtained for all treatments and, except in the case of broadcast granular superphosphate, they are all established as superior to the best rock phosphate treatment (broadcasting). With fine superphosphate there is an indication that broadcasting is inferior to mixing or pocketing but this is not statistically proved. However, for granulated superphosphate, broadcasting and mixing are shown to be significantly inferior to pocketing.

The effect of lime. For all methods of applying rock phosphate liming depresses the response to the fertiliser, significantly so for the mixing and broadcasting methods. Lime has little influence upon any of the fine superphosphate treatments; there appears, however, to be a suppression of the response to granular superphosphate when it is broadcast and mixed, but this is not established statistically.

Chemical Analysis of the Plants

The chemical analysis of leaves, stems and roots showed that the effects of the various fertiliser treatments were very similar in all parts of the plant; for this reason the data given in Table 2 are averages corresponding to whole plants and are expressed as percentages of the oven-dry material.

It will be seen that, in the absence of phosphate (control), liming increased the calcium content and slightly depressed the nitrogen content; little effect is noticeable on the amounts of phosphate, potassium or magnesium present. In the phosphate treatments, however, liming and the type of fertiliser used affected both the calcium and potassium percentages, but had little effect on the amounts of nitrogen, phosphate or magnesium.

The effect of liming is readily seen by averaging the figures for the three different methods of applying the fertilisers, as has been done in Table 3. It is important to note that for both rock phosphate and superphosphate, lime added with the fertiliser increased the percentage of calcium and potassium in the plants, but the total amounts of the elements taken up depend of course on both the composition and the total weight of the plants. Where superphosphate was applied, liming considerably increased the amount of calcium and slightly increased the amount of potassium taken up. On the other hand, plants receiving rock phosphate took up more calcium and much more potassium when no lime was added; this is a reflection of the greater vigour of these plants when grown in the absence of lime.

The chemical data have also been summarised in Table 4, in which the effects of different methods of application in the absence of lime are shown for rock phosphate and granular superphosphate. These treatments have been selected because they are of greater practical importance than the others and they emphasise the point that although superphosphate is superior on average, rock phosphate compares favourably with it for the broadcast method of application. Rock phosphate also provides the plant with more calcium and this is perhaps to be expected, since it is mainly a tricalcium phosphate, while superphosphate is a monocalcium phosphate.

When the two fertilisers were pocketed the percentage of potassium and calcium was higher in the rock phosphate plants but the larger superphosphate plants were able to take up considerably more of both elements. Where the fertiliser was mixed with the soil, rather more potassium was taken up by the superphosphate plants and more calcium by the rock phosphate plants.

Phosphate uptake. Since, as mentioned earlier, many of the plants were beginning to

TABLE 2. EFFECT OF FERTILISER TREATMENTS ON THE CHEMICAL COMPOSITION OF WHOLE RUBBER PLANTS.

Major nutrient elements	Control		Rock phosphate						Granular superphosphate						Fine superphosphate					
			Broadcast		Mixed		Pocketed		Broadcast		Mixed		Pocketed		Broadcast		Mixed		Pocketed	
	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime
% N	1.73	1.55	1.31	1.31	1.36	1.45	1.40	1.46	1.43	1.29	1.37	1.44	1.41	1.44	1.27	1.26	1.40	1.39	1.39	1.52
% P	0.07	0.07	0.09	0.08	0.09	0.10	0.07	0.07	0.09	0.08	0.09	0.09	0.10	0.11	0.08	0.08	0.07	0.07	0.11	0.12
% K	1.07	1.11	0.58	0.84	0.67	0.85	0.72	0.95	0.59	0.64	0.62	0.72	0.55	0.62	0.63	0.75	0.59	0.62	0.52	0.61
% Ca	0.26	0.54	0.38	0.54	0.38	0.54	0.27	0.43	0.23	0.48	0.22	0.48	0.20	0.41	0.23	0.46	0.20	0.52	0.20	0.50
% Mg	0.20	0.20	0.27	0.22	0.22	0.26	0.20	0.18	0.21	0.26	0.24	0.23	0.26	0.27	0.20	0.25	0.22	0.26	0.25	0.29

TABLE 3. EFFECT OF FERTILISER TREATMENTS ON THE COMPOSITION AND MINERAL UPTAKE OF RUBBER PLANTS.

Dry weight and mineral uptake of plants	Rock phosphate		Granular superphosphate		Fine superphosphate	
	No lime	Lime	No lime	Lime	No lime	Lime
Average dry weight (g)	193	117	270	257	298	287
% K	0.66	0.88	0.59	0.66	0.58	0.66
Uptake of K (g)	1.27	1.03	1.59	1.70	1.73	1.89
% Ca	0.34	0.50	0.22	0.46	0.21	0.49
Uptake of Ca (g)	0.66	0.59	0.59	1.18	0.63	1.41

show phosphate deficiency symptoms at the end of the experiment, and since the amount of phosphate added was sufficient for much larger plants, it would seem that much of the applied phosphate had been converted into an unavailable form, assuming that leaching was neglible. It is of interest therefore to calculate the amount of phosphate used by the plants as a percentage of the amount originally added to the pots. The percentage of phosphate present in the control plants was taken to represent the amount obtained by the plants from the soil and from their seed reserve; this has been subtracted to give the figures shown in Table 5.

For the various rock phosphate treatments only 0.3 to 4.0% of the added phosphate was found in the plants, while for superphosphate the figures are from 2.3 to 7.0%. Taken as a measure of the amount of the fertilisers utilised by the seedlings the figures are low, perhaps by 15%, because leaves lost during the experiment have not been taken into account; but it seems that for both fertilisers over 90% is fixed by the soil in a form not readily available to the plant—similar con-

TABLE 4. EFFECT OF METHODS OF APPLYING ROCK PHOSPHATE AND SUPERPHOSPHATE ON THE COMPOSITION AND MINERAL UPTAKE OF RUBBER PLANTS.

Dry weight and mineral uptake of plants	Rock phosphate			Granular superphosphate		
	Pocketed	Mixed	Broadcast	Pocketed	Mixed	Broadcast
Average dry weight (g)	146	185	249	316	281	212
% K	0.72	0.67	0.58	0.55	0.62	0.59
Uptake of K (g)	1.05	1.24	1.44	1.74	1.74	1.25
% Ca	0.27	0.38	0.38	0.20	0.22	0.23
Uptake of Ca (g)	0.39	0.70	0.95	0.63	0.62	0.49

TABLE 5. PHOSPHORUS RECOVERED BY RUBBER PLANTS EXPRESSED AS A PERCENTAGE OF PHOSPHORUS APPLIED AS FERTILISER.

Method of application	Rock phosphate		Granular superphosphate		Fine superphosphate	
	No lime	Lime	No lime	Lime	No lime	Lime
Pocketed	1.5	0.3	5.7	7.0	7.0	6.4
Mixed	2.8	1.9	4.4	3.0	3.7	3.6
Broadcast	4.0	1.3	3.2	2.3	3.2	3.0

clusions were reached by OWEN (1947b) from a previous experiment. However, FRIED AND MACKENZIE (1949) in a pot experiment with legumes grown in a silty-loam soil in America, found figures of 6.5 and 4.8% for rock phosphate but much higher figures (25.2 and 14.2%) for superphosphate. The difference between their figures and those given in this paper conforms with the widely held view (RUSSELL 1950) that tropical soils of the type used in the present experiment fix phosphate in an unavailable form to a far greater extent than temperate soils.

CONCLUSIONS

Considering the average effect of the three different methods of applying phosphate, it must be concluded that in this experiment superphosphate is a better source of phosphorus for rubber seedlings than rock phosphate. If, however, only the methods commonly employed in rubber plantations are considered (namely mixing in the planting-hole and broadcasting on the surface), the difference between the two fertilisers is not great and this second conclusion confirms the results of field experiments and experience in the field generally.

For all methods of applying rock phosphate and superphosphate, it appears that less than 10% of the added phosphate remains readily available to the plant during its early growth. That so small a proportion of the fertiliser phosphate remains easily available for plant growth largely explains why superphosphate is not definitely superior to rock phosphate as might otherwise be expected.

Pocketing superphosphate and broadcasting rock phosphate are established as the most effective methods of applying the two fertilisers in pots. A field experiment to test the efficiency of a combination of pocketing superphosphate at planting-time, followed by broadcasting rock phosphate later, is being considered.

Liming is definitely shown to depress the response to rock phosphate. This may be in part a pH effect, since rock phosphate is more soluble in acidic solutions. On the other hand no pH differences between limed and unlimed treatments were found at the end of the experiment. Since rock phosphate is itself a rich source of lime, the suppression may be partly due to excess of calcium, particularly since it has been shown that the rubber plant has little need of this element (BOLLE-JONES 1954b). Superphosphate contains less lime, and consequently its effect is not in general suppressed by liming.

Rock phosphate plants and those grown with limed superphosphate are both richer in potassium than superphosphate plants grown without lime and it thus seems that the presence of lime facilitates the uptake of potassium by the rubber plant.

In this experiment, establishing significant differences has been made difficult by the large variability among plants treated in the same way. This variability even amongst 'selfed' seedlings, is thought by ROSS (1960) to be mainly genetic and it will necessitate

considerable replication in future experiments in order to establish small effects with confidence.

ACKNOWLEDGEMENTS

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Soils Division
Rubber Research Institute of Malaya
Kuala Lumpur *April 1960*

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Since 1955, certain documents have been duplicated and allotted a serial number as *Archives*. In general, they are research documents which are not suitable for printing in our *Journal*, usually because of the bulkiness of the tabular material or text. In some cases (e.g. Document 1, 6, 10) papers have been published in the *Journal* based on the data deposited in the *Archives*. A few of the documents contain reports of important surveys carried out by the staff of the Institute.

All these documents can be seen at the Library of the Institute. Documents 1 – 9 are held in the form of library copies only. A limited number of copies of the Documents from No. 10 onwards are available on request.

Document No.	Author	Title
1.	E. W. Bolle-Jones and K. Ratnasingam (1955)	Tabulated data on which the paper 'Nutrition of *Hevea brasiliensis* (IV). Interclonal and Seasonal Variation in Composition of Leaves', in *J. Rubb. Res. Inst. Malaya*, **14**(1954) C.257, is based.
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4.	D. H. Taysum (1954)	Microflora of *Hevea* Latex (II). A Compendium of Bacterial Characters.
5.	D. H. Taysum (1954)	Microflora of *Hevea* Latex (III). Some Optical Studies on a Strain of *Serratia Marcescens* Isolated from *Hevea* Latex.
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